EVALUATION OF DUAL-PURPOSE WHEAT VARIETIES IN THE SOUTHEASTERN U.S.

by

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ABSTRACT

Dual-purpose wheat (*Triticum aestivum* L.) systems increase farm sustainability by diversifying on-farm income. While these systems are common in the Southern Great Plains of the U.S., they are not often utilized in the Southeast. This study aimed to evaluate pre- and post-grazing forage biomass of four winter wheat varieties managed under a dual-purpose grazing and grain production system. The wheat varieties evaluated were generic feed-type wheat (unknown variety blend, Feed), seed-type wheat ‘GA Gore’ (Seed) and two forage-type varieties, ‘AGS 2024’ (AGS) and ‘Pioneer 26R41’ (Pioneer). The experiment was a randomized complete block design (n = 4) conducted during the winter of 2021 and 2022. Three grazing frequencies were utilized: an ungrazed control (NG), low frequency (LF), and high frequency (HF) grazing schedule. Low frequency plots received monthly grazing in January and February while HF treatments received a third grazing in March. Plots were grazed with 20 cow-calf pairs (*Bos taurus*) until a constant defoliation height of 10 cm was achieved. Forage biomass was determined using three 0.1m^2-quadrats per plot and clipped to a 10 cm stubble height before (Pre-G) and after (Post-G) each grazing event. Forage samples were then dried at 55˚C for 72 h. Data were analyzed using PROC GLIMMIX of SAS (SAS Inst., Cary, NC) with forage sample date as a repeated measure. Differences were declared at $P < 0.05$. Final biomass, including stems, chaff, and grain, was greatest for Pioneer but was not different from AGS or Feed (4,112 kg/ha and 4,003 kg/ha; $P \leq 0.94$). Prior to grazing, AGS herbage mass (2,646 kg/ha) was greater ($P \leq 0.03$) than all other varieties. There was an interaction ($P \leq 0.01$) of variety and grazing frequency for Pre-G herbage mass. Compared with all other varieties, AGS had greater ADF (24.93%; $P < 0.01$) and least TDN (72.49%: $P < 0.01$). Forage nitrate concentrations were not different among all varieties or grazing frequencies (157.7 ppm; $P \geq 0.49$). Across grazing frequencies, Pioneer had greater final grain yield (3,619 kg/ha; $P < 0.01$) with Seed having the least (1,272 kg/ha; $P < 0.01$). These results indicate that common Southeastern wheat varieties can be successfully utilized in a dual-purpose management system; however, grazing frequency should be monitored to prevent grain yield losses.

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INTEGRATED CROP-LIVESTOCK SYSTEMS

Introduction

Integrated crop-livestock systems, sometimes abbreviated as ICLS, have become a popular method for minimizing economic risks while also incorporating sustainable agricultural practices into what are typically two highly specialized and segregated areas of production agriculture: livestock and row crop production (Franzluebbers, 2007). Due to a variety of external factors, like political, technological, and economical influences, the production of both the crop and livestock sectors have become highly segregated (Hendrickson et al., 2008). Crop production within the U.S. has become highly specialized with the majority of agronomic crops grown being those supported by government programs [e.g., corn (*Zea mays L.*), soybeans (*Glycine max L.*), wheat (*Triticum aestivum L.*), and rice (*Oryza sativa L.*)] (Hendrickson et al., 2008). Similarly, livestock industries for consumer consumption have also become highly specialized, relying on contract sales and vertical supply chains (Hendrickson et al., 2008). The introduction of ICLS has become a reflexive response to mitigating risks due to highly specialized industries. An additional concern of intensification and specialization of our agricultural sectors is the impact to the environment. Many concerns regarding the current state of intensive agriculture involve soil health and nutrient cycling, diversity of both flora and fauna, as well as impacts to the surrounding ecosystems (e.g., waterways and natural areas). The incorporation of ICLS are an alternative to improve resiliency of cultivated lands while improving soil health, mitigating risk by incorporating multiple revenue streams, and reducing the impact farm operations have on surrounding environments.

The characterization of ICLS is highly variable. With significant differences in climate and ecosystems across the United States, and the world, the composition of ICLS can include a variety of livestock species, forages and grassland areas, forestry and silvopasture strategies, as well as various rotations of agronomic crops, such as corn, soybean, rice, wheat, teff (*Eragrostis tef Zuccagni*), peanut (*Arachis hypogaea L.*) and cotton (*Gossypium hirsutem L.*), inclusions of cover crops, green manures, standing hay, crop residues, grazed crop residues, and any number of combinations of these items. Additionally, the implementation of ICLS can vary based on the socioeconomic climate of regions around the world. Entz et al. (2005) provides additional examples and elaborates on implemented ICLS in Africa and China. Many areas within West Africa rely on subsistence production and utilize livestock to improve nutrient cycling in place of inorganic fertilizers which are often not economically feasible. In a similar fashion, regions within western China rely on the integration of livestock to generate additional income by allocating grazing livestock to less erodible soils (Entz et al., 2005). The use of ICLS can also be adapted within rural and agriculture-based areas. Entz et al. (2005) describes the incorporation of ICLS between neighboring farms instead of confined onto one farm. This system of integration between farms may provide more flexibility for producers while incorporating more sustainable practices over time allowing for the adoption of ICLS through small, incremental changes.

Environmental Benefits

Modern agricultural patterns involve highly specialized and segregated agricultural sectors. However, the environmental repercussions of these systems have become heavily scrutinized. With heavy reliance on cheap fuel and fertilizer sources, a separation between key nutrient cycles and provision ecosystem services has occurred (Lemaire et al., 2014; Sulc and Franzluebbers, 2014). For instance, the separation between large-scale, biogeochemical process [e.g., carbon (C), nitrogen (N), and phosphorus (P) cycles), disruption of biodiverse areas of ecological importance (i.e., eutrophication of water ways and lakes, disruption of natural habitats and introduction of invasive species) and deterioration of productive soils and erosion can all be considered consequences of intensive agriculture that occurred in the 20th century and still persists today (Lemaire et al., 2014; Sulc and Franzluebbers, 2014). Recently, a shift in focus has occurred to improving the sustainability and longevity of key agricultural areas.

The main methods in which ecological services are provided by ICLS are described by Sulc and Franzluebbers (2014) in which maintaining soil cover and minimizing disturbances can support soil longevity. The broad benefits to this continuous soil cover are contributed to minimizing runoff of water and applied fertilizers, reduce leaching of nutrients into surrounding ecosystems, improve soil structure (e.g., infiltration, aggregate stability), soil C storage, decreasing competition of opportunistic weed species and interrupting pest cycles, and improving soil biodiversity via cover crop mixes and plant diversity (Franzluebbers, 2007; Franzluebbers et al., 2011).

Manipulation of the biological, physical, and chemical soil fractions can occur when introducing grazing livestock to an area maintained in monoculture. While there are inconsistent results from studies on the impacts of ICLS on soil parameters, particularly regarding compaction (Carvalho et al., 2018), a tradeoff can be considered when incorporating ICLS compared to the traditional, more intensive farming practices. The physical aspects of soil health include indicators such as aggregate stability, presence of macro- and micropores, bulk density, soil strength and penetration resistance (Shah et al., 2017).

Changes in the physical structure of soil and influences from machinery, levels of soil organic matter (SOM), treading from livestock and intensive grazing, water content and soil type can all impact not only the severity of compaction (Hamza and Anderson, 2005) but also the recovery time necessary after physical disturbances. The physical indicators associated with soil health are also closely linked to one another. For instance, an increase in bulk density, the mass of soil per unit volume, is likely to decrease the presence of macropores which are critical for diffusion of gases (i.e., CO_2, NO_2 and O_2) through the soil profile (Nawaz et al., 2013; Shah et al., 2017). Increasing bulk density also decreases penetration of plant roots through the soil profile and increases penetration resistance via penetrometer (Nawaz et al., 2013; Shah et al., 2017) thereby leading to increased compaction levels. Additionally, agricultural areas can become more susceptible to water runoff and have reduced soil water holding capacity because of the absence of macropores available to catch and retain rainfall within the soil profile (Nawaz et al., 2013). Should pastures or crop fields experience compaction that leads to water logging, reduced nutrient availability can be expected when roots are unable to proliferate and reach soluble nutrients (Tracy et al., 2011). Not only can physical restrictions on root growth occur under compacted soils, the presence of O_2 can be limited, potentially leading to anaerobic microenvironments within the soil that can negatively affect plant health (Tracy et al., 2011).

Chemical soil health indicators are closely linked with the physical properties of a soil. The chemical portion of soil health focuses on the biochemical processes that influence plant nutrient availability (Cardoso et al., 2013). For instance, chemical indicators, such as pH, cation exchange capacity (CEC), and electrical conductivity (EC), are often influenced by soil parent material, soil structure, bulk density and water infiltration (Arias et al., 2005) and are considered the primary factors limiting crop yield (Cardoso et al., 2013). Small chemical changes to pH can have large impacts on nutrient availability whereas CEC and EC can also determine ion transformations to plant available or unavailable forms (Arias et al., 2005).

The biological components of soil include many trophic layers of biota as well as the biochemical processes performed by these biotas. Soil organisms include microorganisms (e.g.,, bacteria and fungi), microfauna (e.g., protozoa), mesofauna (e.g., mites) and macrofauna (e.g., ants and earthworms) (Brussaard, 1997). These various classes of organisms provide a variety of services to the ecosystem, such as organic material decomposition and mineralization, nutrient cycling, perforation of the soil profile and creation of channels for gas and water infiltration (Brussaard, 1997). The study of these microbial communities, and the overall biological soil health, has to the due with the evaluation of various soil biological indicators. However, the use of these indicators is not standardized, and dependent on the research goal, their application may change (Mirzavand et al., 2022). Traditionally, indicators such as microbial biomass and enzyme activity have been used to measure the influence of compaction on the below-ground environment and how compaction may influence SOM decomposition, mineralization, and C sequestration (Kabiri et al., 2016). The use of biological indicators is largely based on SOM, and because this measure may take many years to change, the use of microbial biomass and enzymatic activity as biological indicators are thought to be more sensitive to short-term changes, such as an increase in mechanized compaction (de la Paz Jimenez et al., 2002). However, under the effects of grazing, Garcia et al. (2011) reported an increase in enzymatic and microbial activity during the warmer months when beef cattle were allowed to graze compared to treatments that received no grazing.

Grasslands can support a variety of forage species that range in seasonality (i.e.,, annual vs. perennial and warm-season vs. cool-season species), growth habit, nutrient utilization strategies that can support various grazing methods to maintain forage biomass. For these reasons, there is potential for adaptive and dynamic rotations to occur when implementing ICLS. The biologic turnover that occurs in grasslands (i.e., root degradation and proliferation, nutrient supply via feces and urine, diversification of soil fauna) can improve SOM storage via rhizodeposition and accretion of nutrients into plant tissues (Soussana et al., 2004).

Economic Benefits

A key aspect to support the adoption of ICLS is the added resiliency coupled with diversification of revenue sources and income stability associated with industry integration (Sekaran et al., 2021). While whole-farm economic analysis is difficult, and often completed with modeling instead of real-world numbers, some partial analysis and assumptions can be made about the added sustainability production agriculture can achieve when integration is successful. An analysis of farm sustainability completed by Poffenbarger et al. (2017) in the Corn Belt evaluated both cash-only farming systems (i.e., corn and soybean rotation) as well as an integrated system [i.e., livestock, corn, soybean, alfalfa (*Medicago sativa L.*) and oats (*Avena sativa L.*)] and the effect diversification could have on farm profitability. Poffenbarger et al. (2017) concluded that a diversified farming system, including cash crops and livestock, was able to generate competitive profits compared to a grain-only system. When compared temporally, the four-year integrated rotation was able to out-perform the two-year rotation in terms of corn and grain yield However, there are increased concerns regarding labor as a major obstacle for adoption of integrated farming systems (Poffenbarger et al., 2017). Sulc and Tracy (2007) provide a criticism to this point in that there is a potential for integration *between farms* allowing for contractual agreements that synchronize both cash crop and livestock production cycles. This is one method in which producers may spread risk and better utilize labor resources to achieve integration while better managing manure sources and land productivity (Sulc and Tracy, 2007).

Similar analyses have been completed in other regions of the U.S. In particularly arid environments, such as the Great and High Plains there is heavy reliance on irrigated cropland. Allen et al. (2007) provided analysis of the economic viability of traditional, irrigated cotton production versus a rotation of cotton, stockers grazing Bluestem (‘WW-B. Dahl’), and a cover crop of cereal rye (*Secale cereale* L.) and wheat (*Triticum aestivum L.*). Using modeling and given environmental conditions and irrigation requirements, both systems reported negative revenues after costs under drought conditions. However, it was noted that the integrated system assumed a smaller negative return and could be expected to require less irrigation than compared to a monoculture system (Allen et al., 2007).

Additionally, Karn et al. (2005) expanded upon swath grazing in the Great Plains as a means to feed dry, gestating cows during the winter. Swath grazing can be compared to stockpiling in which the last cutting of a late season forage crop is cut, consolidated, usually by windrowing, and left in the field to be grazed by cattle (Aasen et al., 2004). By wintering pregnant cows on swathed corn residue, Karn et al. (2005) were able to achieve the lowest feed cost per head per day compared to swathed wheatgrass and a dry lot, baled hay feeding treatment. While swath grazing can cut labor and machinery costs associated with baling and storing forages obstacles, such as strong winds and access under snow drifts, can become limiting in severe weather (Karn et al., 2005).

Şentürklü et al. (2018) added to the literature and encouraged the grazing of yearling steers in the Northern Great Plains on dual-purpose cropland before feedlot entry to buffer against rising commodity prices and to encourage additional feedlot gains by marketing heavier steers. The potential for added gains upon feedlot entry can encourage producers within the Great Plains to retain ownership of marketable beef calves while also increasing grazed days on pasture, potentially leading to reduced feed costs in the finishing phase (Şentürklü et al., 2018).

Globally, the integration of crop and livestock industries is more apparent. Australia is a common region to practice integrated agriculture. Similar to the U.S., Australia also experiences differing agricultural strategies based on region and climate (Villano et al., 2010). Sandwiched between the ecoregions of high and low rainfall, lies what is known as the "Wheat-Sheep Zone" (Ewing and Flugge, 2004). This region of Australia, which has since expanded to include other facets of agriculture (i.e.,, beef, legumes, and oilseeds), typically involves a blend of continuous crop and pastureland as well as integrated crop/pasture rotations (Ewing and Flugge, 2004). A specific strategy utilized by this region include buffering potential crop losses into temporary pasture areas during dry seasons (Ewing and Flugge, 2004). This allows producers to meet the forage demand for grazing livestock while also limiting crop losses when rainfall is lacking. Canada also utilizes integrated systems to disperse economic risk. Martens and Entz (2011) describe the integration of green manures and the economic impact these systems may have when producers decide to integrate. Additional economic sustainability is incorporated in added body weight gain for meat animals and higher milk production could be expected for dairy animals (Martens and Entz, 2011).

Management Considerations and Uses for Alabama

Integrated crop-livestock systems seek to sustainably match animal nutritive requirements with sustainable forage and row crop options to reduce overall environmental degradation (Franzluebbers, 2007). However, with a greater level of diversification comes an added level of complexity for system management especially given many producers resource constraints. Specifically, the additional burden of managing multiple integrated industries can be a stout obstacle for many who consider ICLS as decisions in one commodity will likely affect the production of other commodities. Therefore, the need to match production seasons of the two industries, as well as coordinate application of soil amendments becomes critical. Identifying what class of livestock can be used and the nutritive requirements of those animals can provide insight into the necessary managerial decisions that need to be made.

With the integration of different agricultural industries, a need for diverse knowledge acquisition is required to maintain the productivity of ICLS because ICLS demand a broad knowledge of crop and livestock production, soil health, and forage crop management. Additionally, the use of specialized equipment and those necessary for implementing no-till or conservation tillage practices can be limiting. Cooperation between multiple producers in a localized geographic area can help to spread financial risk, encourage knowledge transfer and learning, and help spread equipment and labor needs (Russelle et al., 2007).

The main agronomic crops of the Southeast are largely warm-season crops (i.e.,, corn, soybeans, cotton, and peanuts) all of which are also grown as primary cash crops in the state of Alabama (USDA-NASS, 2020). These annual row crops occupy a majority of the spring and summer growing seasons each year and can be rotated with a cool-season annual cover crops in the winter [e.g.,, cereal rye (*Secale cereale L.*), oats (*Avena sativa L.*), and winter wheat (*Triticum aestivum L.*)]. However, given the current market strains and increasing input costs, annual row crop production could prove to be more costly both environmentally and economically (Franzluebbers, 2007; Sulc and Tracy, 2007; Franzluebbers et al., 2011). For these reasons, and given the unique environmental characteristics of the Southeast (i.e., milder winters, sufficient rainfall, and a diverse range of cover crop options), the incorporation of various ICL strategies to be utilized in the Southeast can include: sod-based rotations (i.e.,, rotations the cycle between cash crops and pastures of perennial grasses), the use of short-term forage cover crops, silvopasture (i.e.,, incorporation of timber and cattle production), and intercropping (Sulc and Franzluebbers, 2014). These predominantly row crop-forage rotations allow producers to achieve an extended grazing season for cattle while also rotating row crop areas through a subsequent cover crop or pasture rotation (Franzluebbers, 2007).

Establishing cool-season annuals for grazing purposes is a common ICL of the Southeast (Franzluebbers, 2007). Mullenix and Rouquette (2018) provide discussion on various species and mixtures that can be utilized to meet the nutrient requirements of grazing beef cattle while also reducing the requirement of stored forages. Because feed costs can contribute to as much as 40% of farming expenses for the state of Alabama (USDA-AgCensus, 2017), grazing options provide the cheapest form of livestock-feeding available when compared to feeding stored forages (i.e.,, hay and silage) or supplementation with grains or by-product feeds (Ball et al., 2015).

As of May 2022, there are currently 1.26 million head of cattle in the state of Alabama with the largest group of cattle being mature beef cows (USDA-NASS, 2022). The Southeast predominantly relies on perennial pasture systems to feed grazing beef cows and calves (Dillard et al., 2018; Mullenix and Rouquette, 2018). These may include the use of warm-season species, like bahiagrass (*Paspalum notatum Flueggé*) and bermudagrass (*Cynodon dactylon L.*), as well as cool-season perennials like tall fescue (*Schedonorus arundinaceus Schreb.*). However, when these predominantly perennial pastures have limited forage availability, a variety of annual forages can also be over- or interseeded, to meet the nutritional requirements of most, if not all, growing and lactating beef herds (Dillard et al., 2018; Mullenix and Rouquette, 2018). Globally, of the 6 billion tons of DM demand generated in 2010 to feed the livestock sector, approximately 40% of that demand was supplied with pastures and forages and 13% was supplied via grains (Mottet et al., 2017). In addition to this, approximately 86% of the ingested dry matter consumed by the livestock industry is ineligible for human consumption (Mottet et al., 2017). The U.S. beef industry relies heavily on co- and by-products from cereal grain production (Drouillard, 2018) to meet the nutritional requirements of cow-calf herd. Because off-farm sourced feed costs can account for more than two-thirds of total operating costs (USDA-ERS, 2021), an opportunity has developed in which reducing feed costs can be achieved by incorporating cool-season annuals.

Additional management requirements when incorporating ICLS extends beyond the scope of cash crop and grassland management. It is important to consider additional herd health requirements needed to support the healthy integration of a livestock sector. Proper animal husbandry is necessary to ensure a profitable herd. This includes providing a complete mineral to prevent nutritional deficiencies, providing sufficient access to water, areas of shade, maintaining a proper vaccination and de-worming protocol, keeping adequate records, maintaining an adequate breeding program if not purchasing replacement heifers, weaning calves as well as castrating and dehorning any animals, and overseeing the transportation and re-location of any animals that may be sold. Additional grazing equipment may also be necessary if intensive grazing strategies, like rotation grazing, strip grazing, and limit grazing will be utilized. Evaluation of available on-farm resources, skill sets and managerial capabilities are necessary to begin properly implementing ICLS in the Southeast.

WHEAT

U.S. Production

Behind corn and soybeans, wheat (*Triticum aestivum L.*) is the third ranked row crop grown in the United States as a cash crop. For the 2021/2022 season, the USDA reported approximately 15 million hectares of wheat were planted with a yield of approximately 3 tons per hectare (USDA-FAS, 2022b). In 2021, wheat production for the U.S. had a value of 7 billion dollars (USDA-FAS, 2022a), and while the U.S. is not the top exporter of wheat worldwide, the U.S. steadily supplies about 6-7% of the global supply of wheat (Sowell and Swearingen, 2022). However, in the U.S., planted acreage of wheat is declining. Globally, there is little year-to-year fluctuation in total wheat demand due to developing countries that rely on wheat as a major supply of calories, like India and Southeast Asia (Sowell and Swearingen, 2022). However, local U.S. demand for wheat has fluctuated. This can largely be attributed to changes in consumer palettes and food preferences for diets that include fewer carbohydrate sources (Sowell and Swearingen, 2022), or non-glutenous flour products (e.g.,, almond, coconut, or rice flour) (Houben et al., 2012).

While most wheat production is sourced from the central and western states of the U.S., the eastern seaboard and Southeast also contribute to the total wheat supply. As mentioned previously, the Southeast relies heavily on warm season crop production of corn, soybeans, peanuts and cotton (USDA-NASS, 2020). However, for the Southeast, agricultural areas are particularly susceptible to erosion (Ingram et al., 2013). Incidences of severe weather (i.e., tornadoes and hurricanes) facilitate physical losses of soil resources (Ingram et al., 2013) while sufficient rainfall and warm temperatures lend to loses of soil organic matter via decomposition (Franzluebbers, 2010). Therefore, a major challenge for agriculture in the Southeast is maintaining soil productivity and avoiding soil degradation in an environment that facilitates a year-round row crop production. Management strategies have shifted in the Southeast to largely include conservation tillage, or no-till practices, as well as encouraging the use of cover crops to mitigate depleted cash crop yields (Watts and Torbert, 2011).

Wheat has long been considered a valuable winter cover crop for the Southeast in mitigating erosion (Blevins et al., 1994) and providing residues to capture and sequester carbon (Franzluebbers et al., 1994; Balkcom et al., 2013). Because all other cash crop production occurs in the summer months in the Southeast, establishing and incorporating winter wheat into planned crop rotations provided additional soil cover during the winter months and can provide an interruption to relevant warm season weed species. A winter wheat crop provides an opportunity to avoid additional traffic on productive fields while also providing agronomic and ecological benefits to the system. However, Gardner and Faulkner (1991) have cited that a primary obstacle to the adoption of cover cropping is the lack of “value” associated with a crop that will not be harvested.

Development and Growth

Wheat is a cool season annual crop that can be cultivated in various climates around the world (Briggle and Curtis, 1987). Developed from wild progenitors originating from the Fertile Crescent region (Lev-Yadun et al., 2000; Salamini et al., 2002; Dvorak et al., 2006), modern-day bread wheat was developed from hybridizations between wild emmer wheat (*Triticum dicoccum Schrank*) and a grass relative from the *Aeglipos* genus (*Aegilops tauschii Coss.tr*) (Peng et al., 2011; Nevo, 2014). Early domestication of these wheat predecessors were likely selected for larger kernels, a greater quantity of kernels, ease of threshing, and an improved rachis to withstand harvesting (Salamini et al., 2002; Peng et al., 2011; Jaradat, 2013). All of these traits were cultivated to provide a more harvestable crop. While the genetic mapping of modern-day wheat varieties is complex, these various hybridizations have allowed for the domestication and specialization of wheat varieties based on climate requirements and greater yield potential. Because of this, cultivation of wheat can occur across a variety of climates and regions around the world. Ranging from 30 to 60˚N and 25 to 40˚S (Percival, 1921; Briggle and Curtis, 1987; Phillips et al., 1996), the wheat plant grows best in temperatures around 25˚C but can tolerate a range of temperatures based on cultivar (Phillips et al., 1996).

In addition to tolerance to a range of temperatures, other factors of wheat physiology have been impacted due to domestication. For instance, differences in vernalization, plant height, heading date, photoperiod and tillering capacity have been manipulated (Peng et al., 2011) to yield many different cultivars. However, successful production of wheat is based on the knowledge of wheat physiology and morphology. The main physiological stages of a wheat crop are: germination, emergence, tillering and jointing during the vegetative phase and progress into grain fill and heading during the reproductive phase (i.e., boot to ripening) (Ritchie, 1991; Buntin et al., 2009). The vegetative phase can often range from 60 to 150 days depending on planting date, cultivar, and environment while further development can be counted in growing degree days (GDD) (Acevedo et al., 2006).

Wheat can also be affected by temperatures during vernalization and may be sensitive to photoperiod based on cultivar (Buntin et al., 2009). Vernalization describes a dormant period of cooler temperatures required to induce flowering (Buntin et al., 2009). Winter wheat requires a longer, colder exposure during vernalization than compared to spring wheat (Acevedo et al., 2006); however, the requirement of cool temperatures can often be minimized during short day periods (i.e., winter) (Buntin et al., 2009). This longer vernalization period also lends to greater yield potentials for winter wheat making it the primary choice for wheat production in the U.S. (Vocke and Ali, 2013). Temperatures ranging from 0 to 7˚C for three to six weeks is considered a suitable vernalization period for winter wheats (Ahrens and Loomis, 1963; Trione and Metzger, 1970); whereas slightly warmer temperatures and a shorter vernalization period can be tolerated by spring wheats (Acevedo et al., 2006). This process is an adaptive mechanism meant to delay potential frost injury to the developing seed head; hence, wheat will only begin to flower when proper, spring-time conditions are present (Chen et al., 2009). In addition to vernalization, day length can impact time to flowering in that wheat is often induced to flower as the day lengthens (Acevedo et al., 2006).

Wheat production across the U.S. can be divided into two broad categories based on growing season. Depending on local climate, wheat is classified into spring or winter wheat (Phillips et al., 1996; USDA-FAS, 2022b). Spring wheat production is centralized in cool, arid environments (e.g., North Dakota, Montana and Washington) where summer air temperatures are cool enough to provide a proper environment for wheat production (USDA-FAS, 2022b). Winter wheat production occupies both areas of the Great Plains, (e.g., Nebraska, Kansas and Oklahoma) as well as more northern states (e.g., Idaho and Oregon) (USDA-FAS, 2022b). Regional differences in climate, rainfall patterns and temperatures create unique region-specific cropping rotations meant to optimize crop production. For instance, the Great Plains region of the U.S. relies heavily on dryland agriculture production (Hansen et al., 2012). This region is characterized by low annual precipitation; therefore, unique rotation strategies including reduced tillage and crop residue preservation are implemented to conserve soil moisture and reduce soil degradation (Hansen et al., 2012). These rotations are a change from the predominant wheat-fallow cycle from earlier years that attempted to store rainfall in the soil profile in preparation for a monoculture wheat crop (Hansen et al., 2012). Incorporating reduced tillage practices as well as incorporating short-term summer crops, like sorghum, corn and oilseed crops, has allowed the Great Plains region to adapt its row crop production system to overcome regional resource limitations while reducing environmental degradation (Hansen et al., 2012).

In addition to the seasonality associated with wheat production in the U.S., there are also various classes of wheat that are produced. The classification of wheat kernels is critical because it allows for the standardization and homogenization of wheat flour for baked goods. For instance, classifications of wheat can be identified as “hard,” “soft,” “red,” or “white” and are combined with seasonality identifiers to establish the six major classes of wheat kernels: Hard Red Winter (HRW), Soft Red Winter (SRW). Hard Red Spring (HRS), Soft White (both spring and winter classes) and Durum wheat (Vocke and Ali, 2013). Winter wheats have higher yield potentials when compared to spring wheats due to a longer growing season. Winter wheat is often established in the fall and harvested the following spring in regions where milder winter temperatures can be expected, like the Southeast (Vocke and Ali, 2013). Spring wheats are predominantly cultivated in the Pacific Northwest and Norther Great Plains where extreme winter temperatures and snowfall prevent establishing a winter crop (Vocke and Ali, 2013). The terms “hard”, “soft”, “red” and “white” are identifiers used to describe characteristics of the wheat kernels for milling. Hard wheats are described as those with higher protein content and more starchy endosperm (Vocke and Ali, 2013). These characteristics are needed to support the structure of typical bread shapes. Whereas soft wheats have a lower protein content and are less starchy. Soft white varieties are often used for lighter pastries, like cookies and cakes, that do not require a more developed structure (Vocke and Ali, 2013). Additionally, the variation associated with these classes are often standardized by blending at milling facilities. This ensures a reliable and consistent product for consumers.

Use in integrated crop-livestock systems

Winter wheat has long been used in both ICLS and as an established cool-season forage for cattle (*Bos taurus*), goats (*Capra hircus*), and sheep (*Ovis aries*) (Phillips et al., 1996). The versatility of winter wheat as a cover crop, forage crop and grain crop provides a unique dual-purpose characteristic that has been established since the late 1990’s (Phillips et al., 1996) and is one that has yet to fully explored by producers of the Southeast. In addition to wheat, other cool-season annuals, such as oat, rye, and triticale (*x Triticosecale Wittm.)*, have provided multiple important uses for livestock producers in the past (Phillips et al., 1996).

Incorporating grazed cereal grains in the Southeast has become an established, reduced-cost method to achieving year-long grazing (Mullenix and Rouquette, 2018). The Southeast is dominated by both cow-calf and stocker production; therefore, the need to maintain cow body weight during calving and provide weight gains for growing stockers is key for successful ICL production in the Southeast (Mullenix et al., 2014; Mullenix and Rouquette, 2018). Small grains provide a bimodal phase of production (Mullenix and Rouquette, 2018), accumulating approximately one third of the total DM in the late fall to early winter period (Phillips et al., 1996). The remaining DM is accumulated quickly during the spring as reproductive growth occurs (Phillips et al., 1996). This provides an opportunity to incorporate winter wheat into a predominantly warm-season row cropping region to provide additional grazing opportunities for the cow-calf herd (Mullenix and Rouquette, 2018).

Of the small grains utilized in the Southeast, wheat is both the most cultivated and provides the greatest cold tolerance for winter production (Phillips et al., 1996). Previous literature has provided support for incorporating wheat into grazing strategies for the Southeast. Beck et al (2007) reported greater final body weight of steers grazing wheat when compared to rye or oat alone and average daily gain (ADG) data reported from Mullenix et al (2014) provides support for competitive gains for steers grazing wheat when compared to ryegrass (*Lolium multiflorum Lam.)* and triticale. Mullenix et al (2014) also reported that winter wheat was also able to support an additional 30 grazing days and a higher stocking rate when compared to ryegrass and triticale. In addition to the grazing period of small grains, the nutritive value of these forages may meet, or in some cases, exceed the nutritional requirements of the Southeast beef herd. Nutritional requirements of the cow herd should exceed 52% total digestible nutrients (TDN) and 8% crude protein (CP) while requirements for the lactating cow will increase during peak lactation (Mullenix and Rankins, 2018). For growing animals, TDN and CP requirements increase to meet the energy and protein in order to synthesize new tissue (≥ 65% and ≥ 12%, respectively) (Ball et al., 2015). Winter wheat, depending on variety, can consistently provide sufficient nutritive value to capture stocker cattle gains upwards of 2-lb/day or greater (Gadberry and Beck, 2016).

Utilizing small grains, and in particular winter wheat, in ICLS in the Southeast can lend to additional complexity if grown for a significant grain yield. Because the Southern region of the U.S. receives high levels of rainfall (NOAA, 2022; SRCC, 2022) coupled with prolonged humidity, concerns regarding the spread of foliar diseases can be a concern (Buntin et al., 2009). In particular, the spread of leaf rust, leaf or glume blotch, and powdery mildew are of chief concerns regarding potential yield losses in Southeastern production systems (Buntin et al., 2009). Additionally, potential yield losses due to Hessian fly should also be considered. For these reasons, it is critical to incorporate improved varieties that: a) carry some level of resistance to key diseases and pests, b) have been evaluated by a local State Performance Test for grain yield and c) have been developed for the climate in which they are to be grown (Buntin et al., 2009). Implementing these key strategies can safeguard potential grain yields that are to be harvested and marketed.

Managing fertility is a key driver for yield potential for wheat production. Maintaining proper liming and fertilization schedules is critical when producing wheat on acidic, Southeastern soils. Collecting an annual soil test in a key method for maintaining soil fertility for crop growth. Nitrogen (N) requirements can range from 80-lb/A to as much as 120-lb/A depending on residual N, expected yield, and selected cultivar (Buntin et al., 2009). Requirements for potassium (K) and phosphorus (P) are also variable. Key uptake periods of P and K during wheat production occur before boot and should be provided early in the growing season (Buntin et al., 2009).

DUAL-PURPOSE CROPPING SYSTEMS

Crops for Dual-Purpose Cropping Systems

Available literature documents the use of dual-purpose cropping systems since the late 1950's. These systems function with a goal of maximizing land use and productivity to minimize the separate economic risks associated with specialized production sectors (Bell et al., 2015). There are many regions around the world that utilize dual-purpose cropping systems including Australia, Argentina, China, the U.S., and the Mediterranean. While a variety of crops may be used, the majority of dual-purpose cropping is completed with cereal grains, like winter wheat and rice (Blümmel et al., 2020), as well as oilseed crops such as canola (Bell et al., 2015). Current literature provides resources on the dual-purpose use of canola, wheat, barley, rice and cow pea (Reddy et al., 2016; Blümmel et al., 2020; McGrath et al., 2021). These crops are managed for grazing during their vegetative phases followed by grain harvest provided two marketable sources of income (Bell et al., 2015). Additionally, specific dual-purpose crops that are unavailable to graze until after grain harvest may find additional purpose as a grazed crop residue. This is true for dual-purpose rice in which grazing is completed after grain harvest (Blümmel et al., 2020). Currently, a balance has been established among plant breeding initiatives that seek to manage traits critical of human consumption versus traits critical to livestock production (Blümmel et al., 2020).

In the U.S., dual-purpose wheat is a predominant system used in the Southern Great Plains region (Oklahoma, Texas, and Kansas) in which either cow or stocker herds can graze winter wheat during periods of limited forage availability (Arzadun et al., 2003). However, many obstacles regarding dual-purpose systems involve lack of knowledge and labor resources necessary to manage these two entities. Grazing winter wheat provides excellent forage quality (60% TDN and 15% CP) (NRC, 2016) and forage yield to meet the nutritional requirements of both cow-calf and stocker herds.

Forage yield also becomes a critical factor when supporting winter grazing. Because stored forages are labor intensive and have high costs of production (Troxel et al., 2014), providing long term grazing options may increase producer profitability. Therefore, utilizing cool season forages, especially high-yield species like winter wheat, can provide sufficient dry matter (DM) to reduce winter hay requirements. Results from Marchant et al (2019) report that a mixture of wheat and ryegrass provided the second highest forage mass but was able to support greater grazing days when compared to two other grass mixture. Additionally, when planted early, winter wheat can provide 2,500 kg/ha of grazable forage for the winter herd (Fieser et al., 2006b).

In addition to added gains for the grazing ruminant, dual purpose wheat allows for additional captured profit through grain harvest. During market uncertainties, dual purpose cropping systems allow producers the flexibility to assess which market to play into: grain or livestock. Periods in which cattle markets are unfavorable to sell, producers can offset the impact by selling the harvested wheat grain or producers may store grain to sell when wheat supply is low. The opposite is also true, when the grain market is less than ideal, producers can increase the stocking rate and manage the wheat as a forage rather than as a grain crop (Lollato et al., 2017).

Livestock and Grazing Management

Grazing animals can be maintained on winter wheat pasture in a variety of methods. Traditionally, for the Great Plains region, stocker calves are maintained continuously or are rotated on winter wheat pasture for approximately 120 days (Lollato et al., 2017). For the Southeast region of the U.S., the focus lies heavily on the cow-calf and stocker sectors because of the variety of forage options and mild growing conditions for pasture production (Hoveland, 1986). Incorporating dual-purpose wheat can provide similar grazing days for the winter cow and stocker herds for the Southeast as well. For the cow herd, maintaining body conditions throughout the winter months in preparation for calving protects the future profitable calf crop by maintaining cow productivity through peak lactation. Meeting or exceeding nutritional requirements during lactation supports growth for the calf and reduces weight loss for the cow herd, reducing recovery time necessary before re-breeding. The forage quality also provides a potential for producers that utilize stocker cattle as additional revenue sources.

Stocker herds consist of recently weaned, growing cattle that will be prepared for feedlot entry while on pasture. This includes building immunity and encouraging feed intake before entry into the finishing phase. Other segments of the beef industry, like backgrounding or the feedlot phase, require less pasture space and are able to function in a confined feeding setting relying on a mixture of harvested grains and stored forages. The stocker phase of beef production is a relatively short production period that transitions recently weaned, lightweight calves and prepares them for entry into the feedlot using predominantly forage-based systems (Parish et al., 2008). Stockering seeks to improve immune responses and reduce stress during transition to the feedlot by exposing newly-weaned cattle to feed and water troughs, administering vaccinations, and castrating or dehorning any animals necessary (Parish et al., 2010). Growing cattle that have minimal health issues, are familiar with feed and water troughs, and are of similar stature are desirable because they decrease costs associated with labor and care after entering the feedlot phase (Ward et al., 2019). Yearling, stocker animals require ≥ 65% TDN and ≥ 12% CP (Ball et al., 2015) to maintain positive gains on pasture. Grazing winter wheat may provide most, if not all, stocker nutritional requirements with little supplementation.

When managing dual-purpose wheat systems, it is common to hear references to the first-hollow stem, or FHS, phase during growth. This term describes a critical phase in wheat physiology in which the developing seed head is at or slightly above soil level and can become damaged or removed during close grazing (Redmon et al., 1996; Edwards J.T., 2007). Literature of the Great Plains suggests removing cattle at the FHS stage of production to avoid negatively impacting grain yield (Redmon et al., 1996; Epplin et al., 2000; Fieser et al., 2006a; Edwards J.T., 2007; Edwards and Horn, 2010; Gadberry and Beck, 2016). However, according to Lollato et al. (2017), first hollow stem can vary up to three weeks depending on variety and weather conditions. Additionally, FHS can be delayed by grazing (Edwards and Horn, 2010; Lollato et al., 2017). Depending on management goals, differences in maturity, or occurrence of FHS, can significantly influence final profitability (Edwards and Horn, 2010). Incorrectly selecting an early maturing variety will shorten the number of available grazing days, minimizing potential live-weight gains and may cripple final grain yield if not properly monitored.

Mob grazing, or “mob stocking” as classified by Allen and others (2011), can be defined as utilizing a high grazing pressure for a short amount of time. However, other sources provide a more holistic definition. Heckman et al. (2007) describe mob grazing as a means to improve overall land productivity by maximizing forage productivity and land use via close monitoring. When using the definition provided by Heckman et al. (2007), it can be argued that any form of management-intensive grazing strategy could fall into this category. Therefore, for the purposes of this review, mob grazing will be used to mean a stocking rate for a short duration.

To provide more information, a survey of Midwestern cattle and dairy producers was utilized by Gurda et al. (2018) to expand upon the definition of mob-grazing. Producers from Illinois, Iowa, Minnesota and Wisconsin were surveyed for their definitions of mob-grazing as well as their subjective opinion, whether positive or negative, on the application of mob-grazing. Top survey results indicate that producers define mob-grazing as a high stocking density grazing strategy, using a long rest period and a shortened grazing period.

Management of Grain Crop

In order to mitigate negative impacts to grain yield, careful management practices are crucial (Epplin et al., 2000). Traditionally in Oklahoma, a primary dual-purpose wheat state, winter wheat is planted mid-October; however, due to differences in seasonal temperatures and rainfall patterns, Epplin et al (2000) investigated the effects of planting date on final grain yield. Results from Epplin et al (2000) encourage selection of varieties identified as dual-purpose that may withstand grazing and seasonal environmental stressors (e.g., Hessian fly and disease pressure). Because of the recommended early planting, there is greater risk of exposure and damage from wheat-specific diseases due to warmer temperatures and rainfall patterns (Maulana et al., 2019). Edwards et al (2011) reported a 14% decrease in grain yield for early-planted grazed winter wheat compared to October-sown ungrazed winter wheat. Additionally, grain penalties for grazed, early planted wheat treatments were only 7% less than that of early planted, nongrazed treatments. These results indicate that management decisions and available cultivars play a key role in final grain yield. In general, it is recommended that grazing be initiated approximately 60 days after planting to reduce effects of trampling and provide sufficient root establishment (Edwards et al., 2011; Maulana et al., 2019). Therefore, depending on planting-date, delaying grazing until spring may further mitigate impacts to grain yield.

Seeding rate is often manipulated in dual-purpose systems to mitigate grain yield penalties. Traditionally, a seeding rate of 101 kg/ha is standard for grain-only systems (Lollato et al., 2017). However, in order to mitigate forage and grain losses from grazing and trampling, a 135-kg/ha seeding rate is recommended (Lollato et al., 2017). Fertilization regiments are also altered for dual-purpose wheat production systems. Soil pH is critical to maintaining nutrient availability. Improper pH will affect both forage and grain yields for dual-purpose systems, a range of 5.5 to 6 is a sufficient range for winter wheat production (Buntin et al., 2009; Lollato et al., 2017) When grazed, the additional grazing pressures, loss of leaf area and nutrient loss, create a stressful environment that can negatively affect final grain yield (Lollato et al., 2017). Producers are able to mitigate this stress by providing additional fertility throughout the season. The greater volume of fertilization, for nitrogen, in particular is recommended to be applied in split application from fall to spring (Buntin et al., 2009). Because N is the most growth-limiting nutrient, rates of 112 to 168-kg/ha are recommended to deter yield losses (Buntin et al., 2009; Lollato et al., 2017). Management of P and K, however, are less intensive but should not be overlooked. A single application at seeding to soil test recommendations is often sufficient to meet crop demand (Buntin et al., 2009; Lollato et al., 2017).

ECONOMICS OF DUAL-PURPOSE CROPPING SYSTEMS

The major driver for alternative grazing systems is the economic viability of such systems. While most dual-purpose systems are utilized in the Great Plains, supporting research from both the Great Plains and Southeast may bolster the use of these systems and increase overall farm sustainability. Redmon et al. (1996), describes an unfavorable outcome in which captured cattle gains were unable to overcome net revenue lost during a scenario of unfavorable wheat prices when cattle were allowed to graze 21 days past FHS. This suggests that relying on potential cattle gains may not suffice in overcoming potential yield losses. Using a combined analysis of two data sets, Fieser et al. (2006) and Redmon et al. (1996), Taylor et al. (2010) concluded that the additional cattle gains accrued by grazing past FHS does not offset the loss to wheat grain yield enough to see profit and that removing cattle prior to or at the presence of FHS is crucial.

An increased interest has developed in regard to the management style of these dual-purpose systems, specifically in reference to the associated tillage practices (Watkins et al., 2011). The majority of winter wheat acres are managed under conventional or traditional tillage practices (Decker et al., 2009; Anders et al., 2010). Conventional tillage practices can be described as those in which multiple passes with machinery are made over the cropping area to incorporate stubble, incorporate soil amendments or lime, create a prepared seed bed to encourage sufficient seed-to-soil contact, and to reduce weed pressure. While agronomic areas that are unsuitable for row cropping can often be utilized through cattle grazing, conventional tillage to establish winter wheat pasture can create highly erodible areas (Watkins et al., 2011).

Decker et al. (2009) reported that when comparing two different operation sizes (large vs. small) under different tillage practices (conventional vs. no-till), the early planted (September) planted dual-purpose wheat had the highest net return under conventional tillage. This is in direct contradiction to the results reported by Watkins et al. (2011) in which under three tillage treatments, no-till, reduced tillage, and conventional tillage, no-till management provided the second lowest production costs for wheat forage establishment, the highest steer net return, and the highest steer return above hauling and receiving expenses. Greater return on steers is provided when comparing fall-grazing versus spring grazing (Watkins et al., 2011). This is greatly impart due to the longer grazing period fall-grazed steers are provided as well as additional weight gain (Watkins et al., 2011). Overall, no-tillage provided the greatest return by minimizing return variability while also reducing the added expense of time and fuel associated with conventional tillage systems (Watkins et al., 2011).

Dual-purpose systems have the potential to become as staple in the Southeast as an alternative grazing measure. Both by diversifying operations, reducing tillage practices via no-till or reduced tillage measures, as well as providing additional revenue sources through accrued cattle gains and later grain yield. More research is needed to evaluate varietal performance of common winter wheat in the Southeast as well as specific management recommendations in accordance with Alabaman winter wheat production.

II. EVALUATION OF DUAL-PURPOSE WHEAT VARIETIES IN THE SOUTHEASTERN U.S.

INTRODUCTION

Dual-purpose wheat production systems have been an established winter grazing strategy for livestock in the Great Plains region of the U.S for many years (Dunphy et al., 1982; Winter and Musick, 1991). However, the adoption of this practice in the Southeast has been limited. The Southeast provides an adequate environment to produce cereal grains due to mild winters and adequate rainfall (Sulc and Franzluebbers, 2014). Of the six classes of wheat grown across the U.S., winter wheat dominates due to the regions' mild winter growing conditions. However, planted wheat acreage in Alabama has steadily declined since 2013, a trend similar to other Southeastern states (USDA-NASS, 2022). Therefore, the adoption of dual-purpose wheat systems may provide an advantageous option for producers of the Southeast.

The Southeast relies predominantly on perennial pasture systems [i.e., tall fescue (*Schedonorus arundinaceus Schreb.*), bermudagrass (*Cynodon dactylon L.*), and bahiagrass (*Paspalum notatum Flueggé)*] to meet the nutritional requirements of the beef sector. Therefore, the challenge becomes providing adequate nutrition to lactating and growing animals when warm-season perennial pastures become limiting in the fall. Additionally, because the additive cost of stored forages (e.g., labor, equipment, and time) is the greatest cost for livestock producers, grazing becomes the most cost-effective way to maximize beef production throughout the year, but particularly during the winter months (Ball et al., 2015). Winter wheat is a cool-season annual that provides adequate biomass and nutritive quality for grazing purposes (Dillard et al., 2018).

This creates a unique opportunity for producers to utilize winter wheat as a both a grazeable forage and grain crop. Depending on producer goals, dual-purpose systems provide greater flexibility in on-farm revenue sources by adding gains to young, growing calves and by providing a marketable grain crop in the late spring. Dependent on market conditions and producer resources, the decision could be made to forego harvesting grain to provide additional forage biomass in the early spring, or grazing can be terminated early as to not incur increased yield losses during periods of increased grain prices.

The objective of the current study was to evaluate common Southeastern winter wheat varieties for agronomic performance under three grazing strategies. In order to determine the viability of dual-purpose wheat in the Southeast, a study was conducted to evaluate forage biomass, nutritive value, final biomass, leaf area index (LAI), sward height, and final grain yield of four winter wheat varieties.

MATERIALS AND METHODS

RESEARCH SITE

This experiment was conducted at the Wiregrass Research and Extension Center (WREC) in Headland, AL, U.S. **(**31˚21’25.5”N 85˚19’23.1”W) during the winter of 2019 – 2020 (Year 1) and 2020 – 2021 (Year 2). Soil type was classified as a Dothan fine, sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults). Weather data from each growing season (September – June) were collected and provided via the Auburn University WeatherLink database (https://www.weatherlink.com/; Figures 1 and 2).

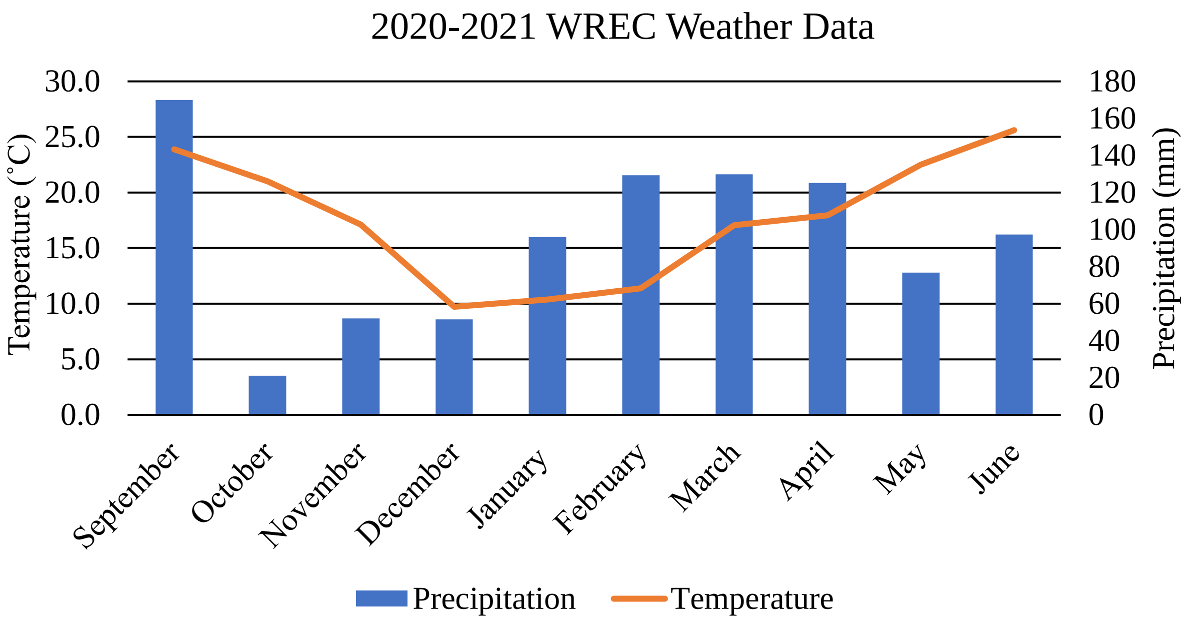

Figure 1. Monthly average temperature (˚C) and total monthly precipitation (mm) for September - June 2020 - 2021 at the Wiregrass Research and Extension Center in Headland, AL.

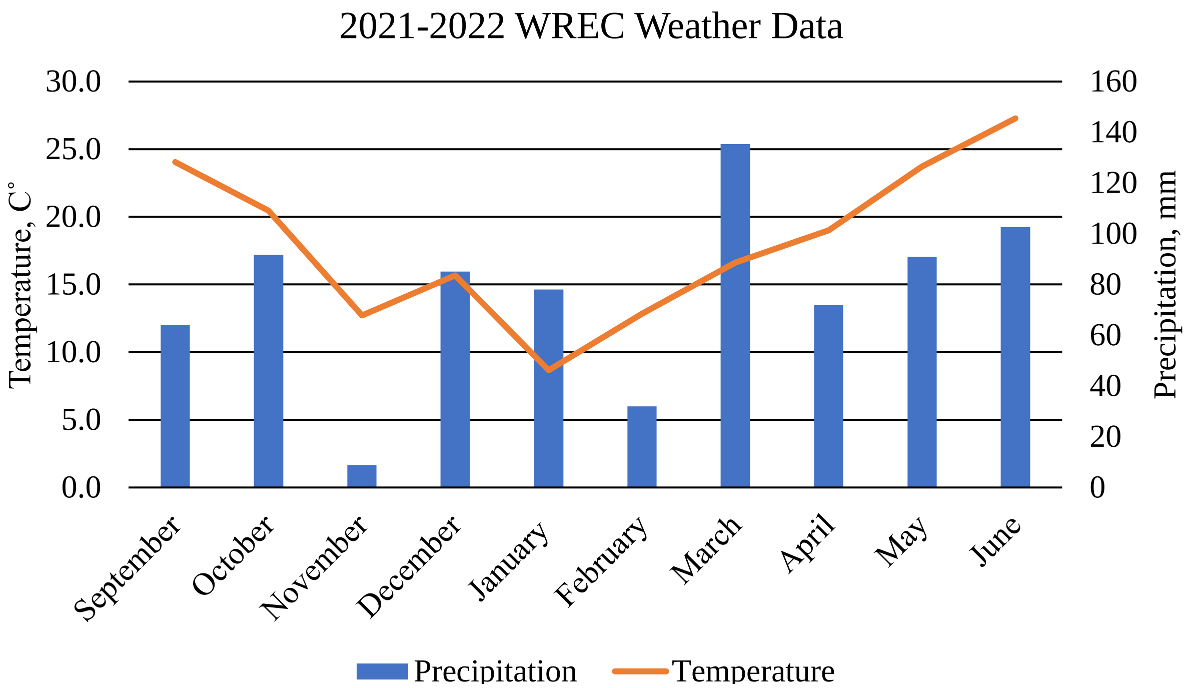

Figure 2. Monthly average temperature (˚C) and total monthly precipitation (mm) for September - June 2021 - 2022 at the Wiregrass Research and Extension Center in Headland, AL.

EXPERIEMENTAL DESIGN AND ESTABLSIHMENT

This experiment was a randomized complete block design with a 4 × 3 factorial treatment arrangement. Treatments consisted of four wheat varieties [AGS 2024 (‘AGS’; Mixon Seed Service, Orangeburg, SC), Pioneer 26R41 (‘Pioneer’; Mixon Seed Service, Orangeburg, SC), Generic Feed-blend wheat (‘Feed’; Taleecon Farmers Co-Op, Notasulga, AL) and GA-Gore (‘Seed’; Hancock Seed, Dade City, FL)] and three grazing strategies [no-grazing (‘NG’), low-frequency grazing (‘LF’) and high-frequency grazing (‘HF’)] replicated in four blocks. Low frequency treatments received two grazing events in January and February at 28 d intervals while HF treatments received an additional grazing event in March. Each block contained twelve, 9 × 9 m plots delineated with temporary electric fencing. Plots were established at 135 kg pure live seed (PLS)/ha using a no-till drill (Great Plains, Salinas, KS) with Year 1 being sown on 2 Nov 2020 and Year 2 sown on 21 Oct 2021. Plots were fertilized with 135 kg N/ha in Year 1 and 2 applied in three split applications (45 kg N/ha per application) across the growing season (October, December, and March). Annual phosphorus and potassium requirements were applied to soil test recommendations.

FORAGE AND GRAZING MANAGEMENT

In Year 1, grazing events were conducted on 12 Jan, 16 Feb, and 15 Mar, 2021 and in Year 2, grazing events were conducted on 18 Jan, 15 Feb, and 12 Mar, 2022. Grazed plots (i.e., LF and HF) were grazed every 28 d utilizing 25 cow-calf pairs (*Bos taurus)* in Year 1 and 20 cow-calf pairs in Year 2. Total live animal weight for pairs in Year 1 was 16,774 kg live weight and 14,437 kg live weight in Year 2. Live animal weight was altered in Year 1 to meet the reproductive goals of the WREC cow herd. Cow-calf pairs were fasted for 18 h prior to each grazing event, then allowed to graze until approximately 10 cm of forage height was achieved. Animals required 4 - 6 h per grazing event dependent on forage availability and total live animal weight.

RESPONSE VARIABLES

Forage Mass and Sward Height

Forage mass was determined using three 0.1m^2-quadrat samples per plot collected prior to grazing (PreG) and an additional three samples per plot following grazing (PostG). In tandem, sward heights were collected PreG and PostG to determine per-grazing heights and to verify target defoliation height. Forage biomass samples were transported to the Auburn University Ruminant Nutrition Laboratory in Auburn, AL and dried at 55˚C for 72-h until a stable dry-weight was achieved. Subsamples were then ground to pass through a 1-mm screen via Wiley Mill (Thomas Scientific, Philadelphia, PA).

Leaf Area Index

Leaf area index (LAI) data were collected during each grazing event and at final grain harvest. Canopy data were collected using an LAI-2200C Plant Canopy Analyzer (LI-COR Biosciences, Lincoln, NE). Leaf area index was determined at three locations within each plot.

Final Biomass and Grain Yield

Final biomass (including stems, leaves and seedheads) was collected using three 0.1m^2 quadrats. Final biomass samples were collected and transported to the Auburn University Ruminant Nutrition Laboratory in Auburn, AL. Final biomass samples were dried at 55˚C for 72 h until a stable dry weight was achieved then weighed for DM determination.

Grain yield was collected from each plot using a Kincaid 8XP single-plot combine (Kincaid, Haven, KS) on 2 June 2021 and 8 Jun 2022 in Year 1 and 2, respectively. Grain yield was collected from the side opposing final biomass collection area. Grain from each plot was sampled in-field for test weight and moisture using a mini GAC® plus handheld moisture tester (Dickey-John, Auburn, IL). Grain yield (kg/ha) was calculated using the equation below:

$$\text{Grain Yield} = [(100 - \text{sampled \% moisture}) \times (0.01) \times (\text{sampled grain weight (lbs)})] / [(\text{standard test weight (lbs/bu)}) \times (1 - \text{standard \% moisture})] / [(\text{plot area})/43560\ \text{ft}^2)]$$

LABORATORY ANALYSES

Forage Nutritive Value

Subsamples from each plot were consolidated and analyzed for total digestible nutrients (TDN), crude protein (CP), neutral and acid detergent fiber (NDF and ADF, respectively). Near-infrared spectroscopy (NIR SpectraStar™ XL; Unity Scientific, Brookfield, CT) was utilized to determine nutritive values at the Auburn University Soil and Forage Testing Laboratory (Auburn, AL). Nutritive value was determined using prediction equations provided by the National Forage Testing Association for small grain forages (NIRSC, 2016). To validate NIR values, 10% of samples were randomly selected each year to undergo wet chemistry analysis.

Samples randomly selected for wet chemistry analysis were evaluated for DM, CP, NDF and ADF. Laboratory DM was determined according to AOAC (1995) at 108˚C for 12 h. Crude protein was determined utilizing the Kjeldahl procedure (AOAC, 1995) using a Kjeltech System (Foss™ Tecator Kjeltech™ 8100, Fisher Scientific, Hampton, NH) for N determination. Crude protein was then calculated by N × 6.25. Neutral detergent fiber and ADF were evaluated via the Van Soest et al. (1991) method using ANKOM 2000® Fiber Analyzer (Ankom Technology Corporation, Fairport, NY).

Nitrate Concentration

Forage nitrate (NO_3) concentrations were determined following the AOAC (1990) procedure, NO_3 concentration was determined with an Orion™ nitrate ion selective probe (ThermoFisher Scientific, Waltham, MA).

ECONOMIC EVALUATION

The economic evaluation for this study seeks to compare potential costs and income associated with a dual-purpose or grain-only production system. Values acquired for total cost calculations were sourced from the current study and include seed costs, fertilizer costs, and equipment costs (i.e., electric fencing, step-posts, gate handles, fence energizer, etc.). Assumed costs not utilized in this work (i.e., calve prices, assumed gain, reduced hay costs) were acquired from additional literature (Runge, 2021). Adjustments for permanent fencing, labor, and wages were also completed. For this study, numerical comparisons are made between a grain-only system versus potential income gained from including calf sales and decreased hay requirements into an example budget. Additionally, while all four varieties of wheat used in this work are included in the total costs, it should be noted that producers will choose only one variety.

STATISTICAL ANALYSIS

Data were analyzed using SAS v. 9.4 (SAS Institute, Cary, NC) for a randomized complete block design. Data were analyzed using the generalized linear mixed model procedure (PROC GLIMMIX). Fixed effects were forage variety, grazing frequency, pre- or post-grazing, and all two-way and three-way interactions. Year was considered a random effect and forage sampling date established as a repeated measurement. A separate model was used for grain yield and final biomass response variables. Fixed effects were forage variety, grazing frequency and variety × frequency interactions and year was considered random. For all response variables, mean separations were performed based on *F*-protected *t*-tests using the LINES options in the LSMEANS statement of PROC GLIMMIX. The α-level for mean differences was set at 0.05. Significant interactions, when $P < \alpha$, were discussed in addition to significant main effects.

RESULTS

BIOMASS AND CANOPY CHARACTERISTICS

Forage Biomass

There was an effect of variety on Pre-G (*P* < 0.01) and Post-G (*P* < 0.05) forage biomass (Table 1). The variety AGS had the greatest numerical difference inf forage biomass (1,810 kg/ha) between Pre-G and Post-G biomass values. Both Feed and Pioneer had intermediary Pre-G forage biomasses that were not different (*P* = 0.69); however, Feed and Pioneer Post-G forage biomass values did differ (*P* = 0.05). Intermediate Post-G varieties were Seed and Pioneer (1,118 kg/ha; *P* = 0.55).There was an effect of grazing frequency on Pre-G (*P* < 0.01) and Post-G (*P* < 0.05) forage biomass (Table 2). Un-grazed controls (NG) yielded only 1.7% greater forage biomass compared with Pre-G biomass samples of LF and HF (*P* < 0.01). Actual biomass difference between Pre-G HF and LF were no greater than 40 kg/ha comparatively (*P* = 0.80).

There was an interaction of variety and grazing frequency for Pre-G forage biomass alone (*P* < 0.01, Table 3). The Seed LF and Seed HF treatments had the least Pre-G forage biomass and were not different comparatively (*P* = 0.78). The AGS, Feed, and Pioneer grazed treatments (LF and HF) were not different among all treatment combinations (1,910 kg/ha; *P* ≤ 0.99). Additionally, the Seed NG treatment was not different from the intermediate grazed and variety treatment combinations (*P* ≤ 0.50). The AGS NG treatment had the greatest Pre-G forage biomass interaction and was different from all other treatment combinations (*P* < 0.01).

Sward Height

Sward height values Pre-G were affected by variety and grazing frequency (*P* < 0.01, respectively; Table 1 and 2). Sward heights Post-G were different among wheat varieties (*P* < 0.03); however, they were unaffected by grazing frequency (*P* = 0.30). Prior to grazing, sward heights were not greater than 40 cm across all grazing treatments and not greater than 42 cm across all varieties. Sward height values Post-G were within 2.5 cm across all varieties and within 6.3 cm across grazing frequencies.

Leaf area index

Prior to grazing, LAI was affected by variety and frequency ($P < 0.01$). Seed-Pre-G LAI was reduced by 1.6% compared will all other varieties. The LF-Pre-G LAI was reduced by 1.1% compared to HF. However, Post-G LAI values were no greater than 0.116 units different across varieties and frequencies (Table 1 and 2).

Final Biomass

Final biomass means were affected by variety and grazing frequency ($P < 0.03$ and $P < 0.01$, respectively). The variety Seed had the least end-of-season biomass compared with all other varieties ($P < 0.02$).

Table 1. Average seasonal forage biomass, sward height, leaf area index (LAI) before and after grazing (Pre-G and Post-G) and end-of-season biomass of four wheat varieties managed as a dual-purpose crop.

		Forage Variety				
	Item	AGS[1]	Feed	Pioneer	Seed	SEM[2]
Pre-grazed	Biomass, kg/ha	2646^{a}	2255^{b}	2180^{b}	1725^{c}	1041.4
	Sward Height, cm	41.8^{a}	$32.1^{b\,c}$	34.2^{b}	30.0^{c}	4.24
	Leaf area index	1.90^{a}	$1.70^{a\,b}$	$1.47^{b\,c}$	1.14^{c}	0.206
Post-grazed	Biomass, kg/ha	837^{b}	1424^{a}	$1063^{a\,b}$	$1174^{a\,b}$	498.0
	Sward Height, cm	13.3^{a}	12.4^{a}	$11.8^{a\,b}$	10.8^{b}	0.62
	Leaf area index	0.41	0.46	0.50	0.39	0.103
End-of-season	Biomass, kg/ha	4032^{a}	3974^{a}	4112^{a}	1534^{b}	693.0

[1] AGS = AGS 2024; Feed = generic variety blend; Pioneer = Pioneer 26R41; Seed = GA Gore.

[2] SEM = Standard error of the mean.

$^{a,\,b,\,c}$ Within rows, means with common superscripts do not differ ($P > 0.05$).

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Table 2. Average seasonal forage biomass, sward height, leaf area index (LAI) before and after grazing (Pre-G and Post-G) and end-of-season biomass of dual-purpose wheat managed under three grazing frequencies.

		Grazing Frequency			
	Item	NG[1]	LF	HF	SEM[2]
Pre-grazed	Biomass, kg/ha	3000^a	1782^b	1822^b	1039.3
	Sward Height, cm	38.6^a	32.8^b	32.3^b	4.22
	Leaf area index	1.88^a	1.34^b	1.44^b	0.195
Post-grazed	Biomass, kg/ha	--	1256^a	992^b	489.3
	Sward Height, cm	--	12.37	11.77	0.46
	Leaf area index	--	0.50	0.38	0.094
End-of-season	Biomass, kg/ha	5409^a	3548^b	1282^c	599.7

[1]NG = no grazing, LF = low frequency, and HF = high frequency.

[2]SEM = Standard error of the mean.

[a, b, c] Within rows, means with common superscripts do not differ ($P > 0.05$).

Table 3. Average Pre-G seasonal forage biomass of four wheat varieties managed as a dual-purpose crop managed under three grazing frequencies.

	Grazing Frequency			
Variety	NG[2]	LF	HF	Mean[3]
AGS[1]	4090	1882	1968	2646^a
Feed	2794	1996	1975	2255^b
Pioneer	2900	1817	1822	2180^b
Seed	2216	1435	1524	1725^c
Mean[4]	3000^x	1782^y	1822^y	

[1]AGS = AGS 2024; Feed = generic variety blend; Pioneer = Pioneer 26R41; Seed = GA Gore

[2]NG = no grazing, LF = low frequency, and HF = high frequency.

[3]Standard error of the mean (SEM) = 1041.4

[4]Standard error of the mean (SEM) = 1039.3

[a, b, c] Within a column, means with common superscripts do not differ ($P > 0.05$).

[x, y, z] Within a row, means with common superscripts do not differ ($P > 0.05$).

NUTRITIVE VALUE

Apparent means for nutritive value parameters are reported in Tables 5 and 6. There was no effect of variety ($P = 0.14$) or grazing frequency ($P = 0.88$) on crude protein values. Crude protein means were no greater than 1.6% different among varieties ($P \geq 0.03$). Non-grazed was not different than HF ($P = 0.98$).

There was no effect of forage variety ($P = 0.11$) or grazing frequency ($P = 0.64$) on NDF. However, ADF means were different across varieties ($P < 0.01$; Table 5). There was no effect of grazing frequency on ADF ($P = 0.28$). There was no effect of forage variety or grazing frequency for ADL ($P = 0.89$ and $P = 0.59$, respectively). Additionally, there was no effect of variety or frequency on ash ($P = 0.75$ and $P = 0.41$, respectively). Total digestible nutrients were different by variety ($P < 0.01$) but not by frequency ($P = 0.28$). Pioneer, Feed and Seed were no greater than 0.37% different; however, AGS was less than 2.56% different from all other varieties. Additionally, forage nitrate means were not affected by variety or frequency ($P = 0.59$ and $P = 0.49$, respectively).

Table 4. Nutritive value of four wheat varieties managed as a dual-purpose crop.

	Forage Variety				
Item	AGS^2	Feed	Pioneer	Seed	SEM^3
CP, %^{1}	19.3^b	20.8^a	20.5$^{a\,b}$	20.5$^{a\,b}$	0.51
NDF, %	49.77^a	47.41$^{a\,b}$	46.98^b	46.78^b	3.112
ADF, %	24.93^a	22.49^b	22.85^b	22.52^b	1.061
ADL, %	5.62	5.49	5.59	5.52	3.487
Ash, %	5.50	5.38	5.52	5.34	3.050
TDN, %	72.5^b	75.1^a	74.7^a	75.0^a	1.11
NO_3, ppm	167.8	160.0	163.1	140.0	34.77

[1] CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, ADL = acid detergent lignin, TDN = total digestible nutrients, NO_3-N = nitrate-nitrogen, ppm = parts per million.

[2] AGS = AGS 2024; Feed = generic variety blend; Pioneer = Pioneer 26R41; Seed = GA Gore.

[3] SEM = Standard error of the mean.

[a, b] Within a row, means with common superscripts do not differ ($P > 0.05$).

Table 5. Nutritive value of four dual-purpose wheat varieties managed under three grazing frequencies.

	Grazing Frequency			
Item	NG[2]	LF	HF	SEM[3]
CP, %[1]	20.2	20.4	20.2	0.44
NDF, %	48.38	47.37	47.45	3.074
ADF, %	23.68	22.95	22.96	1.040
ADL, %	5.65	5.55	5.47	3.486
Ash, %	5.32	5.45	5.54	3.050
TDN, %	73.8	74.6	74.6	1.09
NO_3, ppm	150.5	170.4	152.3	33.94

[1] CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, ADL = acid detergent lignin, TDN = total digestible nutrients, NO_3-N = nitrate-nitrogen, ppm = parts per million.

[2] NG = no-grazing, LF = low frequency, and HF = high frequency.

[3] SEM = Standard error of the mean.

GRAIN YIELD

Reported means for grain yield are shown in Tables 6, 7, and 8. There was an effect of variety and grazing frequency on grain yield ($P < 0.01$). Pioneer had the greatest overall grain yield ($P < 0.01$) and had a 54.0% greater grain yield when compared to the lowest-yielding variety, Seed ($P < 0.01$). The LF treatments were also 64.8% greater grain yield than the HF treatment ($P < 0.01$); however, the LF treatment was different than the NG treatment ($P = 0.05$).

Table 6. Grain Yield (kg/ha) of Four Wheat Varieties Managed as a Dual-Purpose Crop.

Item	*Forage Variety*				
	AGS[1]	Feed	Pioneer	Seed	SEM[2]
Grain Yield, kg/ha	2768^{b}	2677^{b}	3619^{a}	1272^{c}	287.7

[1] AGS = AGS 2024; Feed = generic variety blend; Pioneer = Pioneer 26R41; Seed = GA Gore

[2] SEM = Standard error of the mean.

[a, b] Within a row, means with common superscripts do not differ ($P > 0.05$).

Table 7. Grain Yield (kg/ha) of Dual-Purpose Wheat Managed Under Three Grazing Frequencies.

Item	*Grazing Frequency*			
	NG[1]	LF	HF	SEM[2]
Grain Yield, kg/ha	3,620^{a}	3059^{a}	1074^{b}	251.1

[1] NG = no-grazing, LF = low frequency, and HF = high frequency.

[2] SEM = Standard error of the mean.

[a, b] Within a row, means with common superscripts do not differ (*P* > 0.05).

Table 8. Grain yield (kg/ha) of four wheat varieties managed as a dual-purpose crop under three grazing frequencies.

	Grazing Frequency			
Variety	NG[3]	LF	HF	Mean[4]
[1]AGS	3872	3269	1163	2768
Feed	3766	3290	974	2677
Pioneer	5410	4037	1411	3619
Seed	1430	1640	746	1272
[2]Mean	3620	3059	1074	

[1] AGS = AGS 2024; Feed = generic variety blend; Pioneer = Pioneer 26R41; Seed = GA Gore

[2] Standard error of the mean (SEM) = 287.7

[3] NG = no grazing, LF = low frequency, and HF = high frequency.

[4] Standard error of the mean (SEM) = 251.1

[a, b, c] Within a column, means with common superscripts do not differ (*P* > 0.05).

[a, b, c] Within a row, means with common superscripts do not differ (*P* > 0.05).

ECONOMIC EVALUATION

Reported economic results for this study are presented in the tables below. Table 9 provides a visual partial budget analysis coinciding with a change in management practices. While partial budgets are typically used to evaluate revenue changes, this table highlight non-monetary considerations that are important to consider when changing production methods (i.e., knowledge barriers and infrastructure/equipment barriers). Table 10 reports establishment costs for each variety evaluated in this study, as well as additional costs accrued for management and labor. Calculations are performed in imperial units for ease of understanding. Costs for fertilizer, lime, herbicide and soil testing were those associated with this study and calculated on a per acre basis. Assumed costs (i.e., temporary and permanent fencing supplies, labor and maintenance) were sourced from Extension and academic economic publications (Wilson and Clark, 2002; Edwards, 2012; Runge, 2021). Costs for permanent and temporary fencing are included for dual-purpose production but are removed for grain-only production. Additionally, fencing costs are calculated for one acre of production (i.e., 208 ft × 208 ft = 43,560 ft^2). Total costs in Table 10 does not include seed costs due to annual variability in seed prices. However, this value is included in the final evaluation in Table 12 to provide a complete economic comparison by variety.

Table 11 tabulates potential income associated with calf and grain sales, and factors hay costs that can be associated with a dual-purpose system. Both grain price and calf price are based on historical values ($5/bu and $150/cwt, respectively). Grain yield values for the dual-purpose system were sourced from the LF grazing treatment of this study. Additionally, the grain-only comparison uses the NG grain yield values for each variety. Table 12 provides potential net revenue of four winter wheat varieties when produced in grain-only versus dual-purpose system. It should be noted that net calf revenue is on a per head basis calculated assuming production of 20 calves per acre subtracting the adjusted hay requirements.

Table 9. Schematic of partial budget analysis for switching to a dual-purpose management system.

Switching Production from Grain-Only to Dual-Purpose

Positives	Negatives
+ Additional income from calf gains	- Reduced income from grain loss
+ Reduced hay needs (120d to 09d)	- Establishment costs
+ Reduced drying/hauling costs	- Fencing costs (temporary and permanent)
+ Resiliency under market variability	- Labor/management for cows/calves
+ Co-operative associations between producers	- Knowledge barriers/management obstacles

Table 10. Estimated per acre annual costs for establishment of four wheat varieties managed as a dual-purpose crop.

Variable Costs	Unit	Quantity	Price/Unit	Cost
Seed				
AGS 2024	lbs	100	0.50	$50.00
Feed	lbs	100	0.25	$25.00
Pioneer 26R41	lbs	100	0.50	$50.00
GA-Gore	lbs	100	0.4998	$49.98
Shipping	lbs		1.20	
Amendments				
13-13-13	lbs	300	0.25	$75.00
Lime	lbs	2000	0.02	$40.00
Urea	lbs	175	0.29	$50.75
Soil Test	ea	1	7.00	$7.00
Herbicide	oz	24	0.34	$8.16
Fuel	gal	300	2.70	$810.00
Labor	hr	15	12.00	$180.00
Hauling	bu	by variety	0.55	
Fixed Costs				
Electric Fencing				
Gate Handles	ea	4	5.00	$20.00
Step-in Posts	ea	200	2.70	$540.00
Polywire	ft	2,625	.043	$114.00
Fence Energizer	ac	1	499.99	$499.99
Fault Finer	ea	1	129.99	$129.99
Reels	ea	1	103.00	$103.00
Permanent Fencing				
Barbed Wire – 4 strand with H-braces	ft	208	0.45	$93.60
Labor	ft	208	0.55	$114.40
Maintenance	hr	12	12.00	$144.00
Total Costs	ac	1		**$2,929.89**

Table 11. Assumed net calf revenue, hay costs, and grain yield when grazing a dual-purpose wheat crop.

Item	Unit	Quantity	Price/Unit	Total
Calves	hd	20		
Initial Calf Weight	lb	87		
[1]Final Calf Weight	lb	327		
[2]Sale Price	hd	1	$150/cwt	$490.50
Calf Revenue	hd	20		**$9,810.00**
Hay				
Medium Round, [3]Bermudagrass Hay - Good	ton	31.77	$90	$2,859.30
Hay cost/hd		20		$142.97
[4]Net Calf Revenue	hd	20		$347.55
[5]Grain Yield				
AGS 2024	bu	46.4	$5.00	$232.00
Pioneer 26R41	bu	62	$5.00	$310.00
Feed	bu	46.7	$5.00	$233.50
GA-Gore	bu	17.4	$5.00	$87.00

[1]Assumes 2 lb/d ADG for 120 d.

[2]Price/hd – ACES ProfitProfiles, October 15th, 2021.

[3]Hay requirement for 20 pairs for 90 d. Hay price sourced from ACES ProfitProfiles, October 15th, 2021.

[4]Net Calf Revenue ($/hd) = (Calf Revenue – Total Hay Cost) ÷ 20 head

[5]Assumes average LF grain yield per variety.

Table 12. Revenue comparisons of grain-only or dual-purpose production of four wheat varieties.

	AGS 2024		Feed		Pioneer 26R41		GA-Gore	
	NG	LF	NG	LF	NG	LF	NG	LF
Grain Yield (bu/ac)	55.6	46.4	46.3	46.7	71.0	62.0	17.0	17.4
[2]Establishment Cost ($/ac)	$130.60	$140.96	$127.42	$137.97	$130.56	$141.05	$130.26	$140.80
Net Calf Revenue ($/hd)	--	$347.55	--	$347.55	--	$347.55	--	$347.55
Grain Revenue	$278.00	$232.00	$231.50	$233.50	$355.00	$310.00	$85.00	$87.00
[1]Net Income ($/ac)	$147.40	$438.59	$104.08	$443.08	$244.44	$516.50	($45.26)	$239.75

[1]Net Income = Grain Revenue + Net Calf Revenue – Establishment Costs

[2]Establishment cost includes all variable and fixed costs by variety.

DISCUSSION

Biomass and Canopy Characteristics

Mean forage biomass across all varieties was 2,202 kg/ha. This value is well above the reported DM yield for dual-purpose forage biomass in earlier studies for the both the Southeast (Netthisinghe et al., 2020) and the Great Plains region (Fieser et al., 2006) despite observed dry conditions in Year 2. Across grazed treatments (LF and HF), average forage biomass was 1,802 kg/ha and 1,124 kg/ha for Pre-G and Post-G events, respectively. Similar forage biomass means were also reported by Hossain et al. (2003) but were highly variable due to annual climatic differences. However, similar forage biomass values were reported by Ingram et al. (2014) in which average winter wheat forage yield, when compared to grazed canola treatments, was approximately 1,572 kg/ha. Additionally, winter wheat yields, either grown in monoculture or in mixtures, can reduce DM intake requirements for hay when provided as a winter grazing option (Gunter et al., 2002). The observed biomass values support the use of dual-purpose wheat as a viable option to meet DM intake needs for cow-calf pairs in the Southeast.

Both sward height and LAI are common tools used to measure available forage mass when managing a forage stand that does not require destructive sampling via clipping. The LAI is described as the unit of leaf area per ground area (Fischer, 1966) indicating that a greater leaf area coincides with greater interception of sunlight through the plant canopy thereby increasing photosynthetic capacity. Ingram et al. (2014) reported that when comparing both dual-purpose winter wheat and canola grazing systems in Georgia, grazed winter wheat and ungrazed canola treatments had greater LAI compared to all other treatments, with the highest reported LAI for winter wheat treatments occurring in February and March (1.64 and 1.45, respectively). This data is indicative of the superior biomass accumulation winter wheat expresses during the winter when under grazing pressure.

A reduction in LAI coincides with a conservation of soil moisture by reducing evapotranspiration (Virgona et al., 2006; Harrison et al., 2010). Therefore, removing forage biomass via grazing can be an adaptive strategy for water-limited areas in which available soil moisture can be deferred until grain fill

(Virgona et al., 2006). This strategy has already been utilized within the Great Plains region due to restricted rain fall. Repeated grazing events can decrease overall plant height and remove leaf area necessary for regrowth and grain fill (Poysa, 1985). However, a reduction in plant height may be beneficial by reducing lodging potential and preventing grain loss (Cutler et al., 1949; Poysa et al., 1985; Lyon et al., 2001; Dove and Kirkegaard, 2014). Researchers assessing digestive behavior and grazing dynamics reported, that under three levels of defoliation, winter wheat had the greatest leaf-to-stem ratio when defoliated to 7 cm when compared to a medium defoliation (14 cm) or an ungrazed control (Gregorini et al., 2011).

For the current study, variety differences were apparent in regard to sward height, LAI and grain yield. Pioneer had the greatest grain yield while obtaining an intermediary sward height and LAI. This is indicative of the potential for Southeastern cultivars to recover after consistent defoliations to produce a marketable grain crop. However, it is important to note that cultivar selection is critical for producers who wish to capture the flexibility of a dual-purpose enterprise. For example, GA-Gore (‘Seed’) was developed in the early 1970s and later released in 1990 (Johnson et al., 1993); whereas AGS and Pioneer were both developed and evaluated in recent university-led variety trials (Jordan, 2020); https://officialvarietytesting.ces.ncsu.edu/commercial-wheat-3-year-2016-18/). It should also be noted that utilizing improved varieties also improves resistant to common disease and insect pressure associated with winter wheat. Both AGS and Pioneer display resistance to Hessian fly (*Mayetiola desructor)* and disease resistance (i.e., leaf rust, powdery mildew etc.)

Final biomass encompasses the straw and grain yield of the plant. Final biomass can be indicative of grain yield as well as provide indication of potential lodging and grain losses (Winter and Musick, 1991). Wheat straw can also be utilized as a source of digestible fiber for dry cows during the winter; however, supplementation will likely be required to meet the nutritional demands of higher performing animals (i.e., lactating cows and stocker herds) (Anderson, 1978). In this work, final biomass values for AGS, Feed and Pioneer were no less than 1.5 times greater than the reported Pre-G biomass. Seed was the only variety in which the reported final biomass was less than the Pre-G forage biomass value. This indicates that improved winter wheat varieties marketed as ‘forage’ or ‘dual-purpose’ can withstand consistent grazing pressures and still accumulate adequate final biomass to support a competitive grain yield. Additionally, given the dramatic decline in final biomass in the HF treatment, frequent scouting may be required to avoid significant grain yield losses during the boot stage of production.

Nutritive Value

Reported values of the four evaluated varieties for CP, ADL, and TDN were all greater than those reported by the NRC (2016). However, mean values for NDF and ash were lower than those reported by the NRC (2016). Numerically, mean TDN values were more than 10% greater in the evaluated varieties when compared to the NRC (74.3% vs 61.7%, respectively). These values are adequate to maintain body condition of the lactating beef herd as well as provide growth potential for weaned calves and stocker herds (Ball et al., 2015; Bailey and Thomas, 2021) . Crude protein values were also adequate for the lactating cow herd and for added gains for growing calves. AGS 2024 had the lowest reported TDN and CP of all four varieties and the greatest reported NDF and ADF value. This observation suggestions that AGS 2024 partitioned more resources into forage biomass and cell wall constituents instead of the soluble cell fraction. By comparison, Mullenix et al. (2014) concluded that over a 3-year experiment wheat contained intermediate values for NDF, ADF, and CP (47.0%, 25.0% and 16.2%) when compared to triticale and annual ryegrass. However, investigators also concluded that final steer ADG and grazing days per hectare were greatest for winter wheat compared with the other two treatments, indicating that winter wheat can consistently outcompete other cool-season forages for forage quality.

Nitrate concentration analysis was performed to assess whether high rates of nitrogen fertilization would cause severe nitrate accumulation and potential toxicity. Dual-purpose systems often require higher rates of fertilization to offset potential grain yield losses due to grazing. Cool-season annuals can be susceptible to nitrate toxicity under stressful weather conditions, like reduced precipitation in Year 2 and higher N-fertilization (Ball et al., 2015). Caution is advised when feeding forages with concentrations greater than 5,000 ppm (Ball et al., 2015). However, no observed difference among variety or grazing treatment were evaluated suggesting that even under an increased fertilizer regime, winter wheat remains a reliable and safe forage for winter grazing.

Grain Yield

Netthisinghe et al. (2020) reported grain yield of wheat managed as a dual-purpose crop did not differ from its respective grain-only treatment in both 2017 and 2018 (4,900 vs 5,600 kg/ha and 3,300 vs 3,500 kg/ha, respectively). In comparison with this experiment, similar results were obtained for three of the four varieties evaluated excluding Seed (3,201 kg/ha). Additionally, grain yield for treatments NG and LF were similar to those reported (3,620 kg/ha and 3,059 kg/ha). These observed grain yields were similar to those reported by Edwards et al. (2011) and Butchee and Edwards (2013). In a comparative study with cereal rye, winter wheat, and triticale, Poysa et al. (1985) reported average winter wheat grain yields were greater than cereal rye when exposed to early-jointing or late-jointing forage harvests (2780 kg/ha vs. 1950 kg/ha, respectively).

The evaluated varieties in this study achieved a grain yield of 3,059 kg/ha under the LF grazing treatment with no differences when compared to the NG treatment. By comparison, similar grain yields were achieved by three of the four wheat varieties evaluated in this study (i.e., AGS, Feed, and Pioneer). This observation is encouraging for the implementation of dual-purpose practices due to the attainable grain yields associated with the LF grazing treatment. Dual-purpose wheat can provide reliable winter grazing during key times when perennial pastures may be limiting (i.e., December to February).

Economic Evaluation

Calculated costs in this work are meant to provide a baseline for future evaluation of dual-purpose cropping enterprises. Costs for seed, labor, supplies and amendments will vary based on seasonality and location. Calf gains and marketing values in this work are assumed values based on local enterprise resources, and while these are assumptions, may provide a baseline for dual-purpose wheat producers in the Southeast to evaluate dual-purpose production for their own use. Further economic evaluation and sensitivity analysis is required to provide a complete picture of economic viability. However, values reported in this work dissent with previous literature regarding expected net returns of dual-purpose cropping systems (Epplin et al., 2001). Duke et al. (2011) reported that simulated expected net returns for a dual-purpose cropping system were to be greater than its comparative grain-only system, but a lack of in-field trials requires more investigation into the accuracy of dual-purpose economic evaluation.

CONCLUSION

Results from this work indicate that dual-purpose wheat enterprises may be a successful winter grazing strategy for the Southeast. Improved varieties adapted to the Southeast can potentially withstand 60 days of grazing before severe grain yield losses occur. However, more work is needed to evaluate more intensive grazing strategies for dual-purpose wheat in the Southeast. This includes the use of rotational or continuous grazing which is a common practice for cow-calf producers. Additionally, identifying the maximum achievable BW gain for growing calves grazing winter wheat would be beneficial for producers to make accurate estimations of potential profit when marketing weaned calves. Depending on producer goals, grazed winter wheat can provide an adequate source of forage biomass and forage quality for the grazing cow-calf herd. Additionally, dual-purpose management provides flexibility by providing maximum forage biomass or grain yield, dependent on producer needs.

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